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A Survey of Alternative Energy Sources with a Specific Focus on Solar Energy

Introduction:

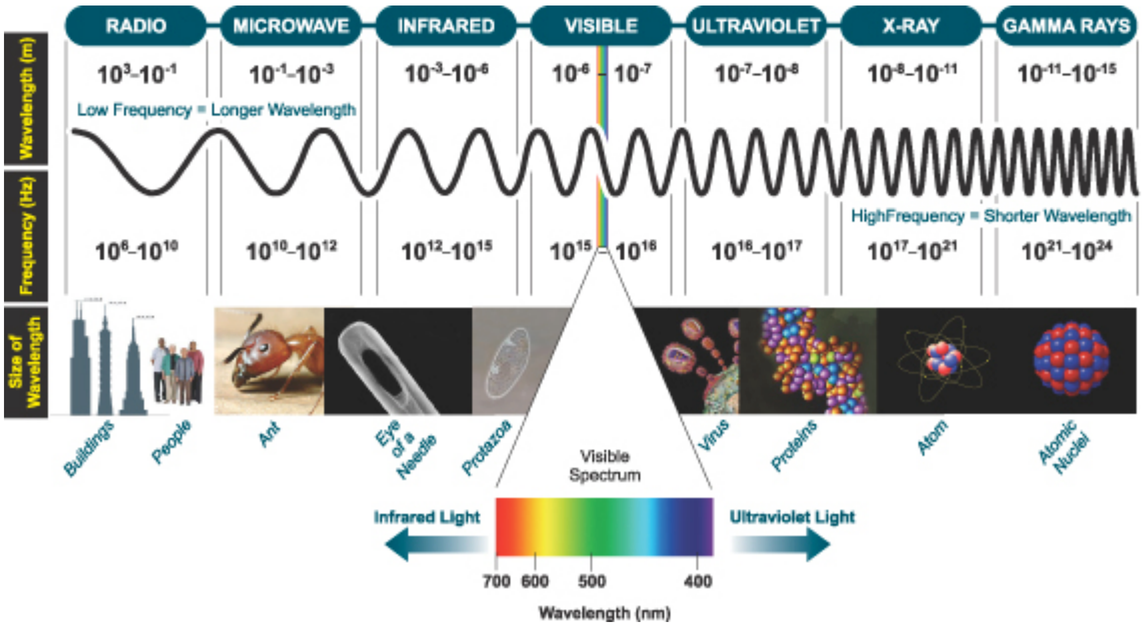
The purpose of this project is to design materials for use in a middle school science class to introduce alternative sources of energy, explain the importance of investigating alternatives to fossil fuels and to explain how solar energy can be used to produce electricity. The first section of this paper is intended to provide general information about the importance of investigating and implementing alternative energy sources as well as to provide information about how solar power works and how it is produced. The second section of the paper will address student misconceptions about alternative energy sources and provide materials that can be used to teach middle school students about alternative sources of energy.

The Source of Our Energy: The Sun

The sun is the largest object in our solar system, containing approximately 99.8% of the mass. It is composed predominantly of two gases, hydrogen (70%) and helium (28%). The sun provides energy that supports almost all life on Earth*, which is released through the process of fusion (Arnett, 2006). During fusion in the sun, two hydrogen atoms are joined to form a helium atom, but since the helium atom is less massive than the two hydrogen atoms, the remaining mass is converted to energy which is released (Freudenrich, 2007). The energy is released in small bundles of energy called photons that travel in waves. These waves of energy are categorized by their wavelength in the electromagnetic spectrum. Figure 1 is a diagram showing the electromagnetic spectrum. Approximately 4.6×10^{20} joules of energy, an amount equivalent to the annual energy use of humans, reaches the Earth from the sun in about a day and a half (Crabtree & Lewis, 2007).

* Ecosystems have been found around geothermal vents, where there is no sunlight and hydrogen sulfide-oxidizing bacteria form the base of the ecosystem’s food chain, using chemosynthesis rather than photosynthesis to support life (United States Geological Survey, 1999)

Figure 1: The Electromagnetic Spectrum



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Earth: A Nice Place to Call Home

The Earth is the only planet known to support life. There are various reasons why life is able to survive on our planet: liquid water, the atmosphere, and it is not too hot nor is it too cold. The greenhouse effect is a natural process that helps regulate the Earth's temperature. Solar radiation that penetrates the Earth's atmosphere either heats up the Earth's surface or is reflected. The heat that is absorbed also gets radiated back into the atmosphere, and is trapped by gases, causing the Earth's temperature to rise. The gases that are responsible for this heating are known as greenhouse gases, some of which are naturally occuring. A list of the six greenhouse gases observed by IPCC (Intergovernmental Panel on Climate Change) and their sources is found in Table 1.

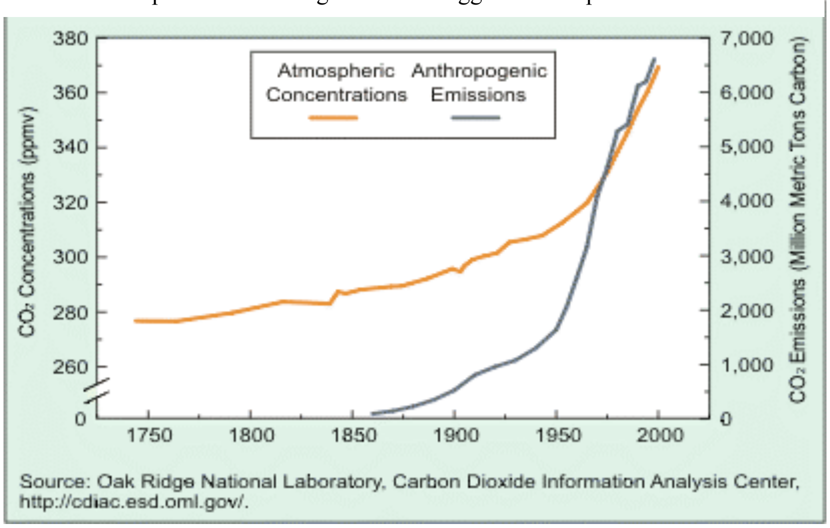
Table 1: Greenhouse Gases and their Sources (from Energy Information Administration, 2005)

Abbreviation/ Symbol	Name	Common Source	U.S. Emissions 2005
CO_2	Carbon dioxide	Burning fossil fuels, solid wastes and wood, concrete production	6,008*
CH_4	Methane	Landfills, burning fossil fuels, livestock, natural gas production and distribution	612**
N_2O	Nitrous Oxide	Burning fossil fuels, fertilizer, manure, nylon production	366,569**
HFC's	Hydrofluorocarbons	Refrigeration gases, aluminum smelting, and manufacturing of semiconductors	138**
PFC's	Perfluorocarbons	Cleaning products and manufacturing of semiconductors	7**
SF_6	Sulfur hexafluoride	Aluminum smelting, manufacturing of semiconductors, and electronics industry	16**

*Measured in metric tons.

**Measured in carbon dioxide equivalents. Carbon dioxide equivalents are units used to express emissions of greenhouse gases if the equivalent amount, by weight, of carbon dioxide gas was released. This is calculated by multiplying the gas's GWP (Global Warming Potential) by their emissions in metric tons. GWP allow for easy comparison of various greenhouse gases when compared to carbon dioxide. It takes into account their relative heat absorbing capacity (Energy Information Administration, 2005)

Figure 2: Trends in Atmospheric Concentrations and Anthropogenic Emissions of Carbon Dioxide
http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html



Levels of carbon dioxide in the atmosphere have risen dramatically over the last 50 years, as shown in Figure 2. "During the past 20 years, about three-quarters of human-made carbon dioxide emissions were from burning fossil fuels (National Energy Information Center, 2004)." Car exhaust accounts for roughly one third of the emissions, another third from coal for producing electricity, and the remaining emissions are from miscellaneous sources such as industrial processes (Sweet, 2006).

Between 1970 and 2004 there was a 70% increase in global greenhouse gas emissions, which have been increasing since pre-industrial times. If the current trends continue it is predicted that carbon dioxide emissions may grow between 40 and 100% by 2030 (Metz, et al 2007).

During the mid-1990's climate scientists came to a consensus that the world was warming at an alarming rate and that the rise in temperature had anthropogenic causes. Increased levels of greenhouse gases are believed to be the primary cause of global warming, especially carbon dioxide. The relationship between atmospheric carbon dioxide levels and mean global temperature is illustrated in Figure 3. Global warming is predicted to cause plant and animal species to migrate and some to become extinct because of loss of habitat, oceans will become more acidic because of increased absorption of carbon dioxide, glaciers and snow caps are disappearing, sea levels will rise and threaten coastal areas, and stronger cyclonic storms are predicted (Sweet, 2006). The United States is the biggest single source of greenhouse gas emissions in the world, producing about one quarter of the world's greenhouse gases and "the country best positioned to do something about them (Sweet, 2006)".

Currently 80-85% of the world's energy comes from fossil fuels with the majority coming from coal, 11% is supplied by biomass, but over two thirds of that is being harvested without being replaced. Solar heat accounts for 0.3% of the global heating for space and water and 0.015% of the world's electricity is supplied by solar power (Crabtree & Lewis, 2007). Why is so much energy provided by fossil fuels? It is cheap, but with rising oil prices and fewer new deposits being discovered each year, that may change.

The Need for Alternative Sources of Energy

There are many problems stemming from our dependence on fossil fuels. One, we have to rely on imports from other countries for much of our fossil fuels. The United States imports 60% of its daily oil consumption, adding up to $300 billion per year and by 2025 it is predicted that we will import at least 70% of our oil (Sawin et al, 2006) A second reason is that fossil fuels are a limited resource, they will eventually run out and the discovery of new reserves has decreased. Energy demand is predicted to increase by two thirds over the next thirty years and electricity demands are predicted to double if no effort is made to conserve energy and if less developed countries become more advanced, demanding more electricity (Sweet, 2006). Third, as stated previously, burning fossil fuels increases the level of greenhouse gases in the atmosphere, which contributes to global warming. A fourth reason is the environmental impact of extraction and transportation of fossil fuels. For these reasons, it is necessary to investigate alternatives to fossil fuels. Possible alternatives include geothermal energy, wind energy, solar energy, hydropower, tidal energy, hydrogen, and biomass. A summary of these energy sources currently used for electricity production as well as those being investigated can be found in Appendix A. The remainder of this paper will focus on solar energy.

Harnessing the Sun's Energy:

The four main methods that humans have used to make use of solar radiation include passive solar design, active solar, solar thermal power, and photovoltaics. Passive solar design is the most cost effective because no additional materials are needed beyond typical construction costs and works with two goals: absorb heat in the winter and avoid it in the summer. It involves using specific design elements and construction materials to take advantage of heat from solar radiation. Possibly the most important element is building a structure with large windows that have a southern exposure to allow heat from the sun to enter during the day. Materials that will absorb heat during the day and then slowly release it at night are used for construction and the structure should be designed to allow heat to spread using the natural processes of conduction, convection, and radiation. It is also important to control overheating in the summer, which can be accomplished by planting trees to shade the northern side of the house or using design elements such as roof overhangs, awnings, trellises, or blinds to block sunlight (Pahl, 2007).

There are two options when implementing active solar, one is domestic hot water and the second is space heating. Both options use solar collectors to heat water (or another heat-transfer fluid in space heating) which is then stored for later use. A domestic hot water uses the collectors to heat water that is then used for domestic use and if necessary, it can be further heated with a conventional hot water heater. When using active solar for space heating, the heat-transfer fluid is circulated through the house to provide heat (Pahl, 2007).

Solar thermal power is utilized for large scale energy production. Solar power plants, such as Nevada Solar One in the Mojave Desert, can use variations of two different designs. One design involves rows of mirrors that concentrate the sun's energy on a central tower where

Figure 4: Nevada Solar One
http://www.daviddarling.info/encyclopedia/S/AE_Solar_One.html

air is heated, as the heated air rises by convection, it turns turbines which produce electricity. A similar design uses mirrors, either an array or a series of troughs, to concentrate the sun's energy on a liquid that absorbs the heat and is used to heat water to produce steam to turn turbines that produce electricity (Solar Development Inc., 2002).

The final method for utilizing solar radiation is through the use of photovoltaic cells. Photovoltaic cells, also referred to as PV cells or solar cells use a process called the photoelectric effect, in which a semiconductor is used to convert solar radiation directly to electricity The specifics of this method will be further discussed in the following sections.

The Photoelectric Effect and Photovoltaic Cells

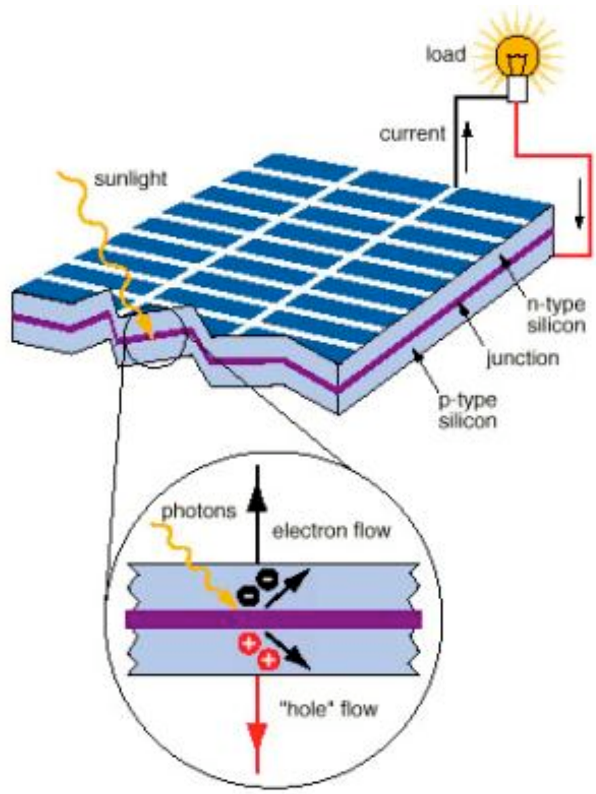
In 1839, Alexander-Edmund Bequerel, a French physicist observed that certain materials produce a current when exposed to sunlight, this process is known as the photoelectric or photovoltaic effect. Photovoltaic or PV cells make use of this phenomena to produce electricity. When sunlight hits a PV cell it is either reflected, passes through the PV cell, or it is absorbed. Energy, from the absorbed photons of light, is taken up by electrons of a semiconductor in the PV cell. The electrons become excited and leave their normal location and jump into the "conduction band", meaning the electrons have enough energy to be in the range of energies where quantum mechanics dictates that it can move freely through the silicon lattice of the semiconductor without much chance of capture because its energy is in the "band gap". The freed electrons creating "holes" or positively charged regions in the semiconductor and can wander through the semiconductor by having neighboring electrons fall into them and thus transmit the hole to a neighboring atom. The mobile electron-hole pairs move under the influence of the electric field in the diode in the n-side or p-side (respectively) generating an electric current (U.S. Department of Energy 2006).

The semiconductor most often used in PV cells is silicon. Silicon is a metalloid that has an atomic number of 14, which means that it has 14 electrons arranged in three shells. The outermost shell contains four electrons, which means silicon atoms are able to form four bonds with other atoms. Pure silicon will form a crystalline structure so that each silicon atom shares electrons with four other silicon atoms in a repeating pattern. Pure silicon is not a good conductor of electricity because all of its electrons are tightly bound to other atoms, so they will not easily move, so impurities are added to silicon used in PV cells. A common "impurity" that is added to silicon for use in PV cells is phosphorus. A phosphorus atom contains five valence electrons, so it can form three bonds with other atoms. When phosphorus is added to silicon, it does not bond with four silicon atoms, only three, so one electron is not paired, so when energy is added to the impure silicon, the non-bonded electron in phosphorus can leave the phosphorus atom. A hole is created when the electron leaves and the electron wanders until it finds another hole to fall into, these wandering electrons are called free carriers, which can create an electric current (Markvart, 1994).

The process of adding impurities to a semiconductor is called doping. When phosphorus is added to silicon, the silicon is called n-type (negative-type) because of the number of free electrons that can be released. Boron, an atom with only three valence electrons is also added to silicon, creating p-type (positive-type) silicon, because it will have numerous holes or positive regions. In a PV cell, the p-type silicon is layered with n-type silicon, creating an electric field because the free electrons on the n side try to travel to the p side to fill the holes that are present. The electric field creates a diode, which is a device that allows electrons to flow in one direction and blocks the flow in the other direction. When electrons are freed in the semiconductor, the electric field pushes the electrons to the n-side and the holes to the p side (Markvart, 1994).

Silicon is a shiny material that will reflect a great deal of sunlight, which reduces the amount of energy that can be absorbed, so an antireflective coating is applied to the top of the silicon. A contact grid is placed on top of a layer of n-type silicon and a protective glass cover is placed on top. A layer of p-type silicon is placed below the n-type silicon and a back contact is placed below that. The contact grid and the back contact connect to a load to allow the electric current to flow through it. Several PV cells can be connected to make a PV module amd several modules can then be connected to make an array (Markvart, 1994). Figure 5 shows a diagram of a typical PV cell.

Figure 5: A Photovoltaic Cell
http://www.rise.org.au/info/Education/SAPS/sps003.html



Limitations of Photovoltaic cells

Most PV cells have an efficiency of only about 18% or less. Energy loss in a PV cell constantly occurs and current research is focused on reducing energy losses. If a photon does not have enough energy to knock an electron loose, it will be lost. If a photon has more than enough energy, then the extra energy will be lost. These two occurrences account for over 70% of the energy loses of a PV cell. The amount of energy needed to knock electrons loose is known as the band gap energy, which is an inherent property of semiconductors. Energy is also lost because the contact grid that is placed on top of the n-type layer of silicon, which is needed to allow the flow of electrons, blocks some sunlight (Markvart, 1994). Research is being aimed at designing contacts that do no block incidental radiation and also at making use of energy that is above the band gap. Adding texture is another method that is being researched to provide additional opportunities for incidental radiation to be utilized.

PV cells are expensive, due to somewhat low efficiency; a large number of modules may be required for electricity productions, which would require a large area to mount the panels. Materials are needed to support the panels, which can become heavy and require additional support if mounted on a roof (Markvart, 1994).

The sun's energy is not constant throughout the day, year, or global distribution. Careful analysis must be made to determine the best angel for the panels as well as to determine if an area receives enough solar radiation to produce the desired electricity. Solar radiation varies around the globe because of the tilt of the Earth. Regions of the globe that are tilted toward the sun will receive more direct radiation than those positioned away from the sun, so for example the northern hemisphere would have the most direct radiation during the summer months when it is angled toward the sun and less during the winter months, while the opposite is true for the southern hemisphere. Regions near the equator receive fairly constant radiation as evident from Figure 6. (Trebel, 1995).

Figure 6: Global absorbed radiation in January and July
http://eesc.columbia.edu/courses/ees/slides/climate/swrad.gif

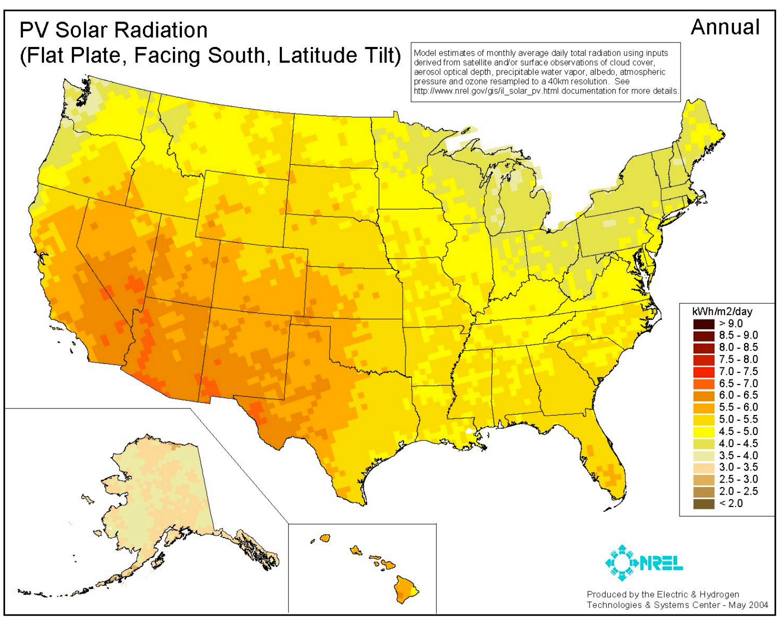
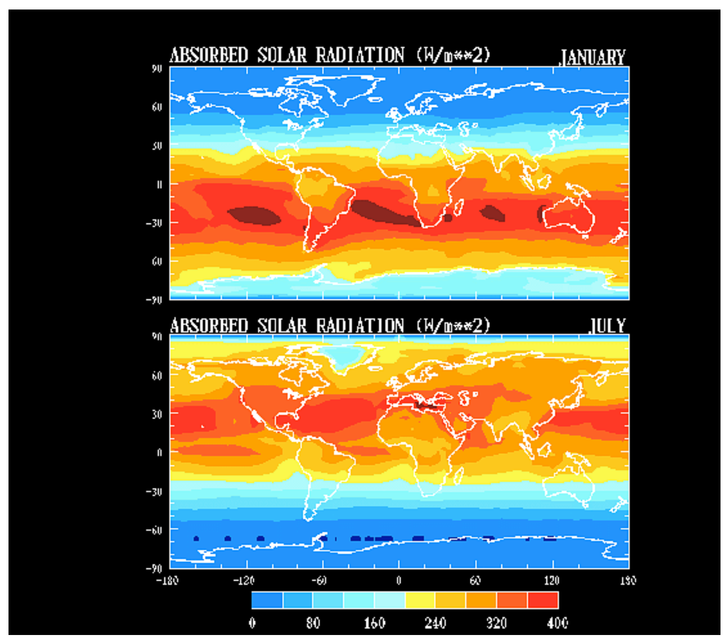


Figure 7: Solar Radiation Map
http://www.solaroregon.org/learn/oregon-solar-resource



A map such as the one in Figure 7 can be consulted to determine the intensity of sunlight for a given region to help ascertain whether or not solar power is a viable option for that region. If solar panels are mounted, they have to be positioned so that they are not shaded by trees or other structures and angled so they receive the most direct solar radiation during the middle of the day. This usually means that they need to be pointed toward the equator at an angle that is related to the latitude of the region (Treble, 1995).

Technology and Research: The Future of Solar Power

Current research in photovoltaics is focused on two main goals: cost reduction and improved efficiency. There are many avenues being investigated to meet these objectives including improving first-generation PV cells, investigating new semiconductor materials, use of nanotechnology, hybrid cells, organic solar cells, thin-film cells, and polymers as well as techniques that are combinations of all of these materials.

It was once believed that the first-generation of PV cells, would be replaced by the second-generation of solar cells, which primarily involve thin-film technology. The second-generation of solar cells would then be replaced by the third-generation of solar cells, which would produce high efficiency solar cells that could be produced at low costs (Crabtree & Lewis, 2007). This is not the case. Research is ongoing in the three generations of solar cells and no one type of technology seems to be taking the forefront and is the clear future of solar electricity production.

In an effort to utilize greater wavelengths of light, techniques such as hybrid solar cells use various semiconductors that absorb different wavelengths of light, layered together. Flexible materials are being created that can conform to any shape and can be used as roofing materials or can be incorporated into various building materials (Kuwano, 1995). Spray-on solar cells have been developed using nanotechnology and polymers. This material can create solar panels out of almost any surface and could be used to paint cars or buildings and allow them to produce their own electricity. Fabrics could be treated with the material, allowing you to produce electricity with your clothing or any other material (Lovgren, 2005). This is one path that could be very beneficial to the military because tents could become sources of electricity and could be easily transported allowing for easy charging of computers or other communications devices.

Dye sensitized cells make use of nanotechnology to create flexible sheets of solar cells that can be stamped onto a material as easily as printing a magazine. This technology functions in a similar fashion as photosynthetic pigments and would be an inexpensive method for producing solar cells (Crabtree & Lewis 2007).

Devices that make use of nanotechnology, thin-film technology and dye sensitized materials may reduce costs because support structures that were needed for first-generation PV cells would not be necessary, these materials are light weight so buildings would not require additional support for heavy PV panels, they may be produced from inexpensive and non-toxic materials, and could be incorporated into building materials that would already be necessary and could simply do "double duty".

Conclusion

There are numerous reasons why alternative sources of energy need to be investigated. Our dependence on foreign oil and other fossil fuels must be reduced. Burning of these fossil fuels releases large quantities of greenhouse gases into the atmosphere and by reducing these emissions the process of global warming may be slowed. The fossil fuels that we are so dependent to for our electricity production are a non-renewable resource with a limited supply that will eventually run out. Global electricity demand is steadily increasing. Old coal-burning power plants are less efficient and release large amounts of pollutants including mercury, greenhouse gases, as well as emissions that contribute to acid deposition and there is the environmental impact of obtaining, transporting and processing fossil fuels (Environmental New Service, 2007).

Alternative energy, such as solar power, provides the opportunity for reduced greenhouse gas emissions as well as reducing our dependence on fossil fuels much of which comes from foreign sources. First generation solar panels have proven to be reliable sources of electricity. Some panels are over 20 years old and are still functioning at near their original capacity. They require little maintenance, are silent, and have little environmental impact. It provides a direct conversion of sunlight to electricity without any moving parts but other technologies may provide more efficient and flexible options for alternative electricity production. Continued research in these avenues is necessary for the sustainability of our society and the planet.

Appendix A: Summary Energy Sources

Energy Source	Description	Source of GHG	% U.S. Energy Production in 2000
Coal	Fossil fuel that is burned in power plants heat water to turn turbines to produce electricity	Y	46%
Nuclear	Uses energy released by radioactive elements to heat water to turn turbines to produce electricity	N	18%
Natural Gas	Fossil fuel that is burned in power plants heat water to turn turbines to produce electricity	Y	14%
Hydroelectric	Energy from flowing water is used to turn turbines to produce electricity	N	7%
Oil	Fossil fuel that is burned in power plants heat water to turn turbines to produce electricity	Y	5%
Biomass	Biomass in the form of wood, organic wastes such as methane, or grasses are burned to produce electricity	Y	1%
Wind	Wind turbines or wind mills convert wind energy to electricity	N	<1%
Solar	Use solar radiation to produce electricity or heat homes or water	N	<1%
Geothermal	Heat from the interior of the earth is used to heat homes or produce electricity	N	<1%
Tidal	Underwater turbines harness energy of the tides to produce electricity	N	*
Wave	Motion of the waves is used to produce electricity using standard hydroelectric techniques	N	*
Ocean Thermal	Using temperature differences in the ocean water to drive electricity producing machinery	N	*

* Not a significant source of electricity production, may be theoretical or experimental

Source for energy sources: Pahl, Greg. (2007) *The citizen-powered energy handbook community solutions to a global crisis*. White River Junction: Chelsea Green Publishing Company.

Source for percentage of electricity production in 2000: North American Working Energy Group, 2002

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